Search for trilepton SUSY signal at CDF

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Why Physics Beyond the Standard Model?

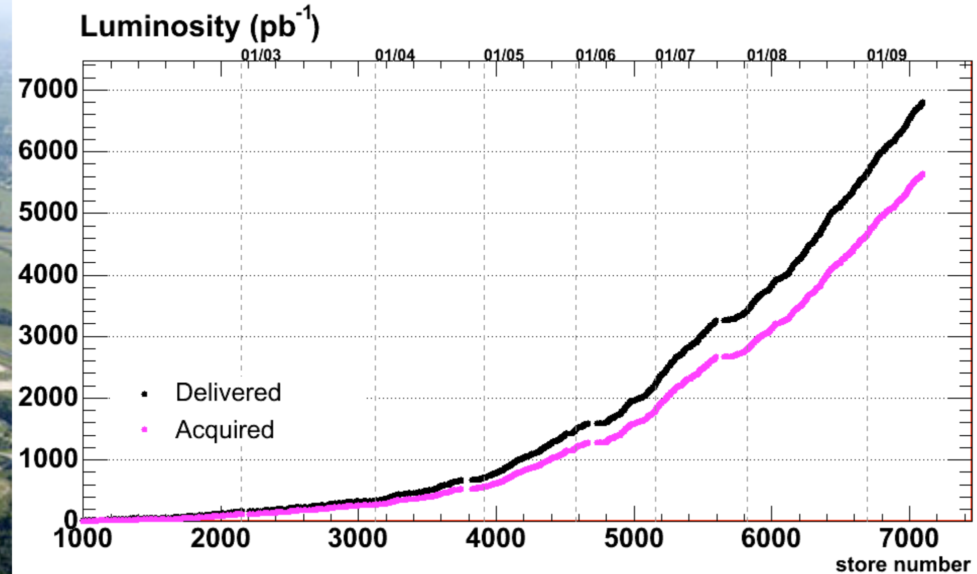
- Although extremely successful, the Standard Model does not answer all our basic questions about nature
  - Why is the Planck scale and the electroweak scale 17 orders of magnitude apart?
  - How is gravity incorporated?
  - What is the origin of mass?
  - What is the source of dark matter?
  - Why there is a boson/fermion asymmetry?
  - Why there is a particle/antiparticle asymmetry?
  - Why we have several interactions instead of one unified one?
  - ….

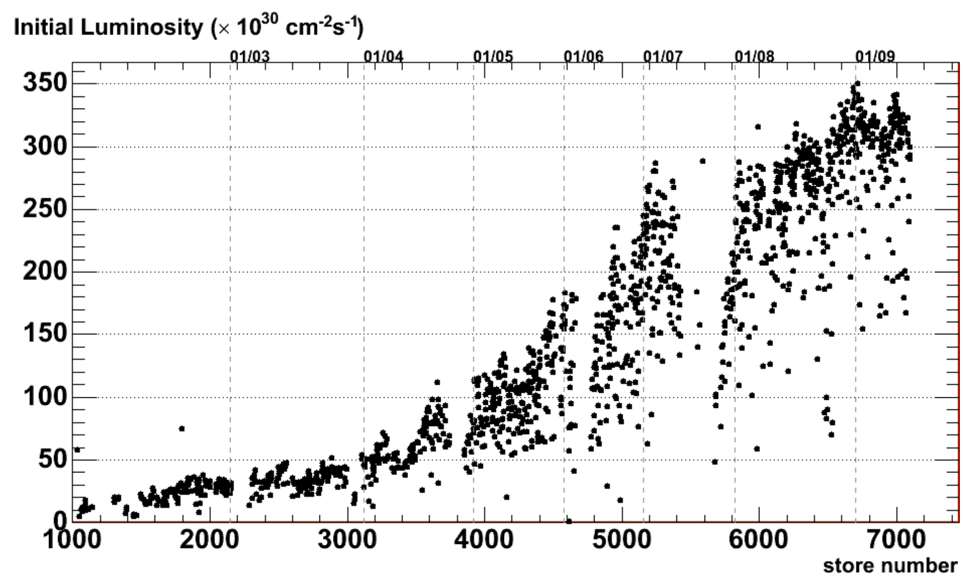
- Our job as experimentalists is
  - to perform experiments to discover new-physics effects that could give answers to the above questions
  - to perform experiments to test current theories that offer answers to the above questions

Supersymmetry

- Theory that predicts a boson for any SM fermion and vice-versa
  - The superpartners differ only in their spin
  - The superparnters of the gauge bosons and the higgs mix to create the charginos and neutralinos which are fermions
- SUSY is obvioulsly broken, which leads to a new mass-spectrum for sparticles. We study "soft" SUSY breaking
  - mSUGRA (LSP=neutralino), GMSB (LSP=gravitino)
- Removes fine tuning and offers ultra-violet completeness
  - Large radiative corrections of superpartners cancel each-other
- Offers possibility of force unification
  - Not exactly possible with SM
- Offers a cold dark matter candidate
  - If the lightest supersymmetric particle (LSP) is stable. This is the case if R-parity is conserved
- Possibility of radiative Electroweak symmetry breaking
  - As an alternative to spontaneous breaking

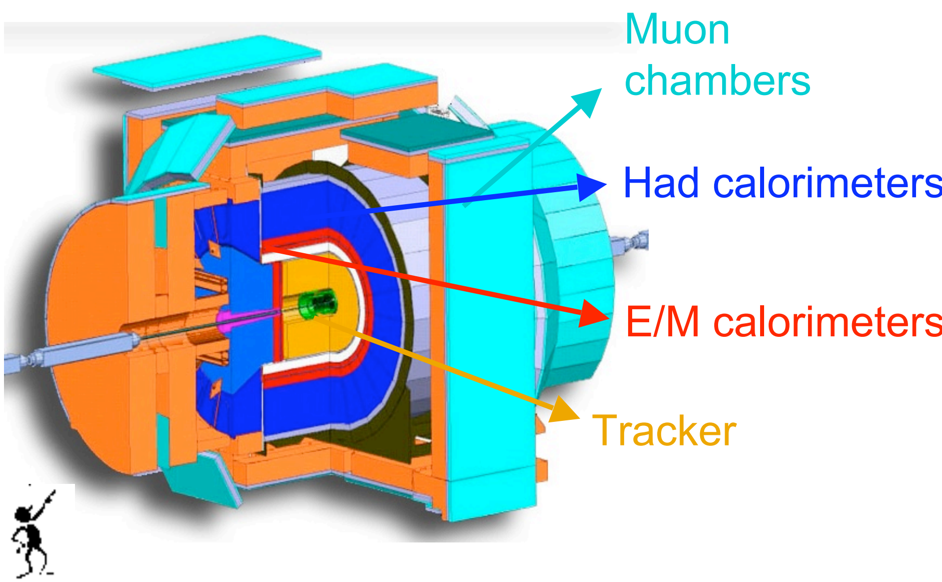
The Tevatron



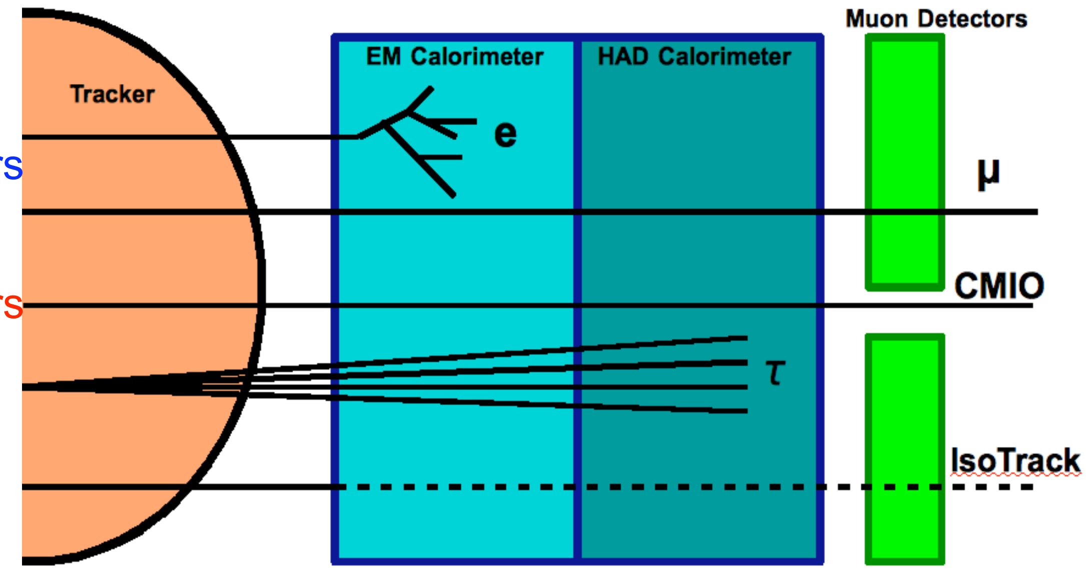


- Tevatron is still the highest-energy hadron collider (protons-antiprotons at 1.96 TeV CM)
- Instantenous luminosity routinely reaches 325 x 10^{30} cm^{-2} s^{-1} (max ~ 350)
- Recorded luminosity: > 5.5 fb^{-1}
- Presented in this talk: 3.2 fb^{-1}

The CDF II detector



Lepton definitions

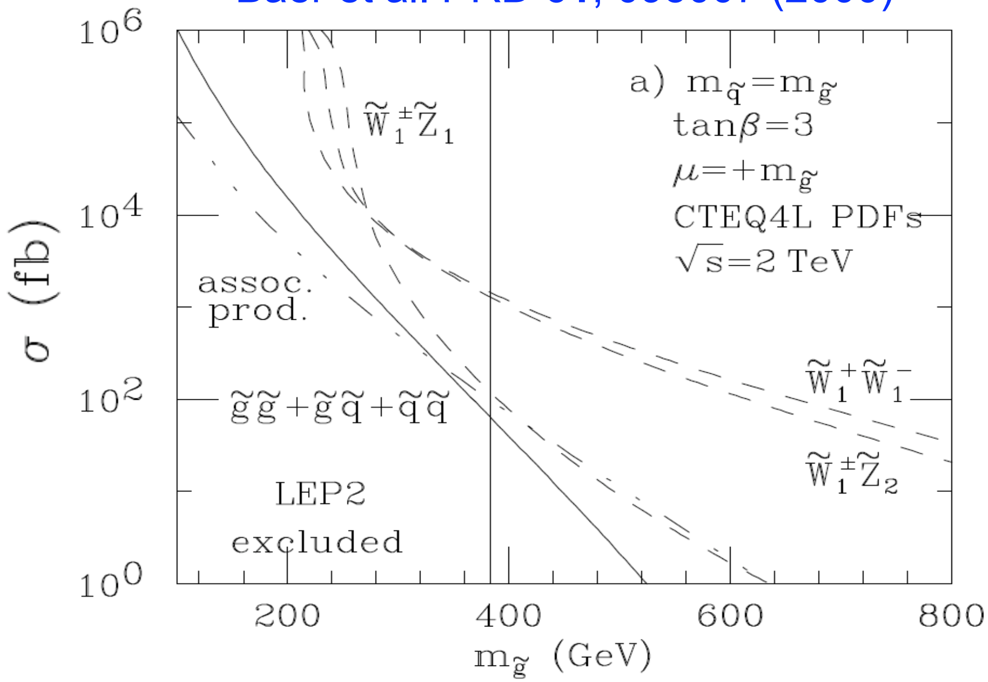


- Central tracker measures charged particle trajectories
- These trajectories are matched to calorimeter energy depositions and hits in muon chambers to reconstruct electrons and muons
- Hadronic Jets (from outgoing quarks and gluons) and imbalance in transverse momentum (MET) are also determined with the calorimeters
  - MET is indication of particles that do not interact with our detector

Why chargino-neutralino, why trileptons?

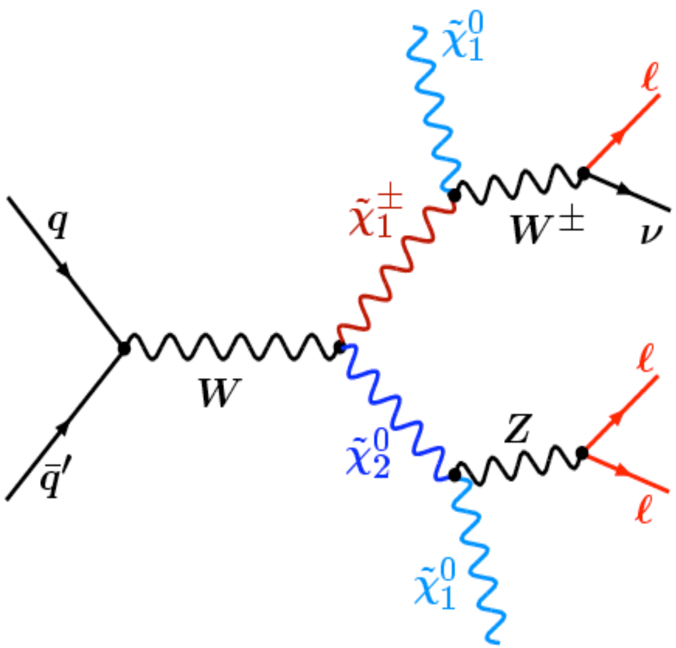
- The non-excluded chargino-neutralino production cross-section at the Tevatron is of the order of 0.1-1 pb, depending on the SUSY parameters

Baer et al. PRD **61**, 095007 (2000)

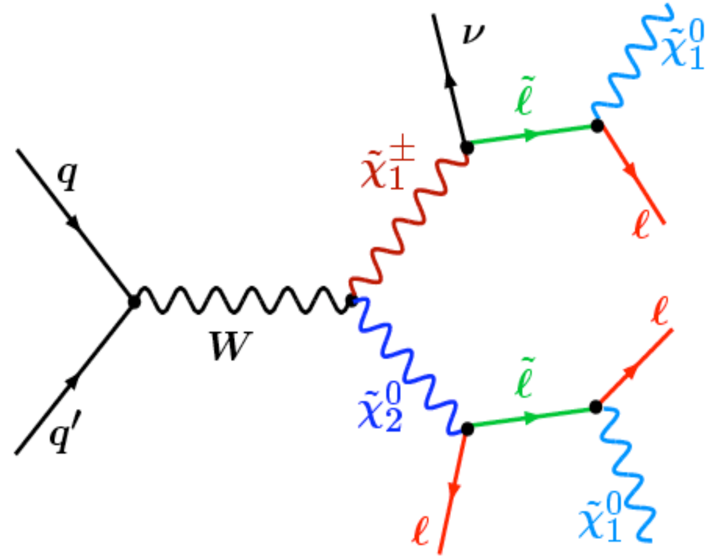


- The leptonic decays of the chargino and the next-to-lightest neutralino give ***3 leptons and MET***, a signature with low SM backgrounds.
- For these reasons, the trileptons are ***the golden channel for the discovery of SUSY at the Tevatron***

Trilepton chargino-neutralino signal



Decays through W/Z favorable for heavy sleptons, but BR to leptons low

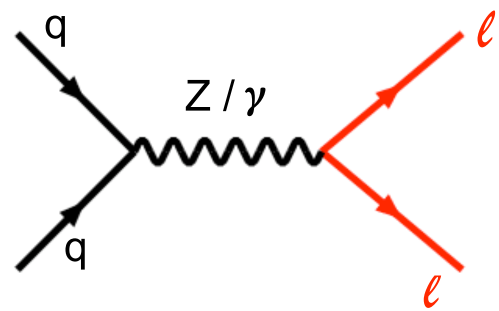


Decays through sleptons guarantee final leptons, but also preference to τ

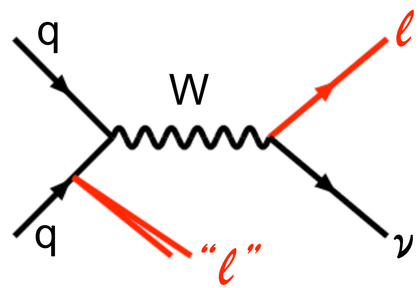
- Both cases give the signature of interest: ***Three leptons and Missing Transverse Energy*** (MET) due undetected neutralinos (LSP in mSUGRA with R-parity conservation) and neutrinos

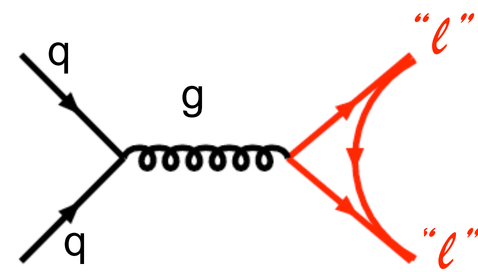
SM Dilepton Backgrounds

- Electroweak
  (Drell-Yan)
  Measured with MC simulation

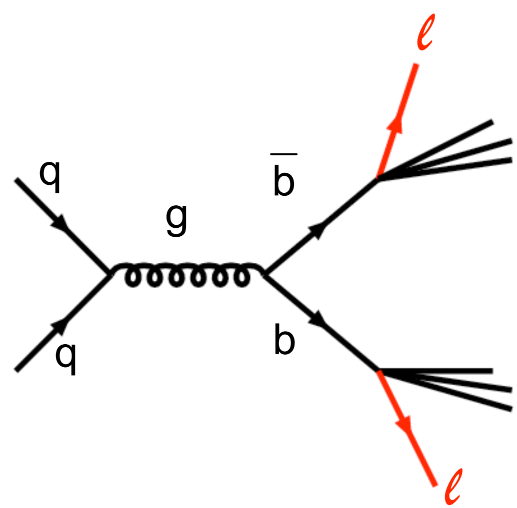


- Light-flavor QCD
  (u,d,s quark-based)
  Measured with CDF data





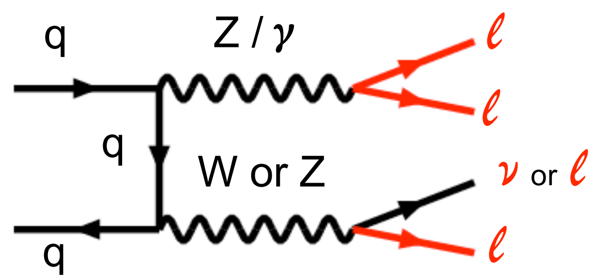
- Heavy-flavor QCD
  (c,b quark-based)
  Measured with CDF data

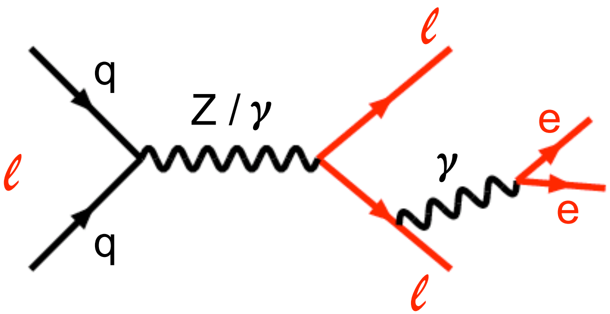


"ℓ"= fake lepton

SM Trilepton Backgrounds

- Electroweak
  (Drell-Yan+γ and diboson)
  Measured with MC simulation





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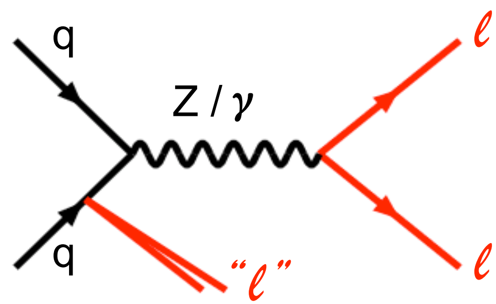

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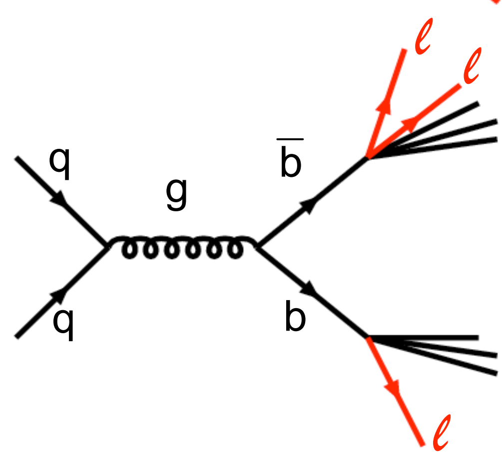
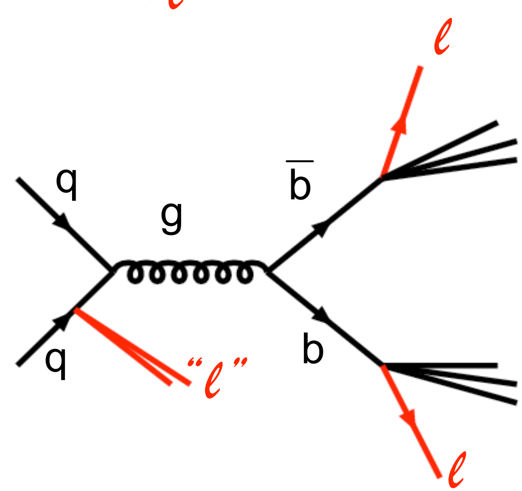




"ℓ" = fake lepton

Analysis strategy

- Unbiased (blind) analysis:
  - We define control regions where we validate our SM backgrounds
  - We look at the signal region only after control-region background validation

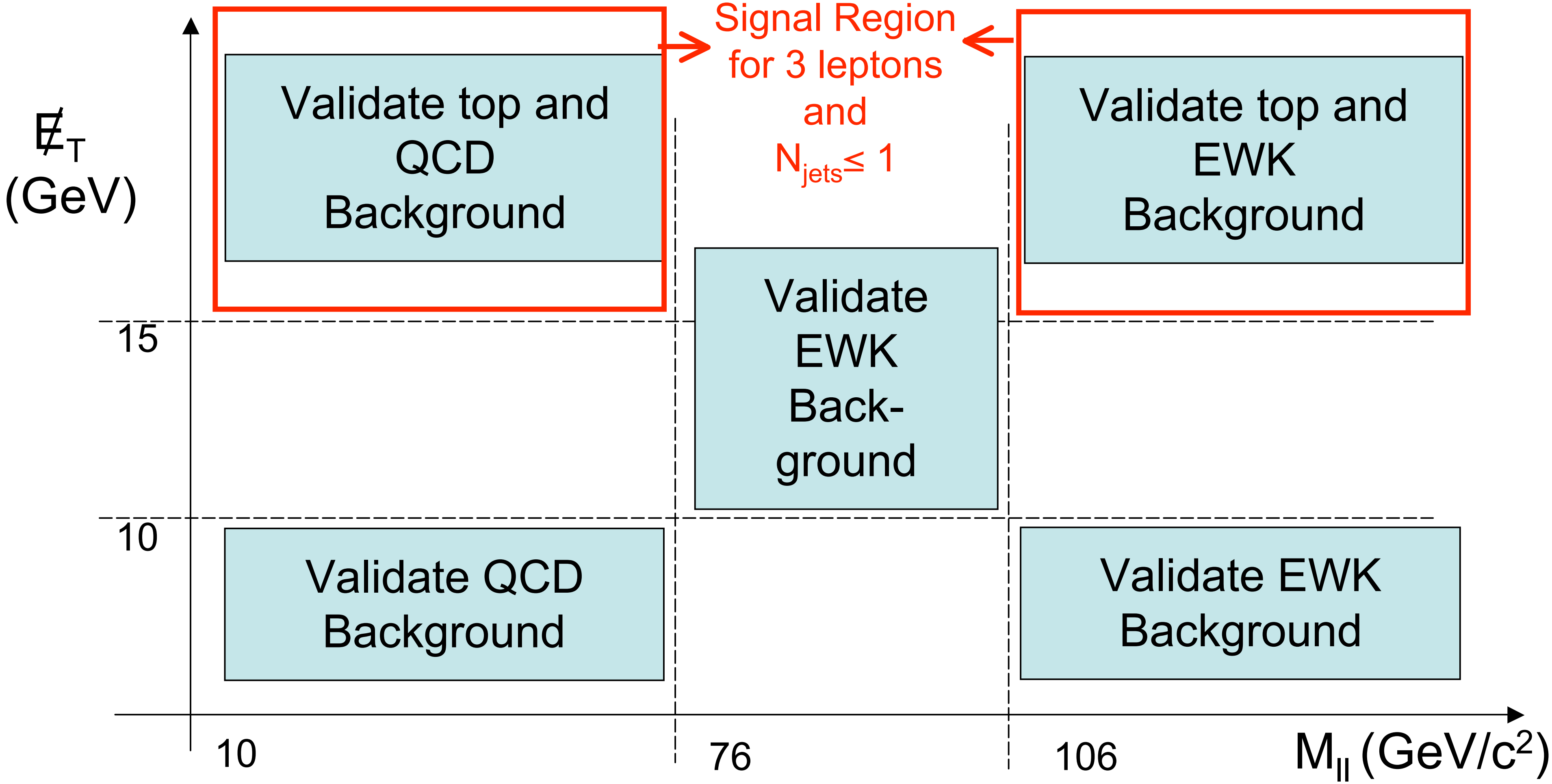
- Control regions:
  - Investigated dilepton and trilepton control regions in MET-M_{ll}-N_{jet} three- dimensional kinematic space
    - 15 control regions overall

- Signal region:
  - Keep it as simple as possible (based on background minimization) and don't over-optimize (to do both SUSY testing and generic discovery)

Datasets and event selection

- Luminosity: 3.2 fb^{-1}
- Low-p_T (≥4 GeV/c) dilepton triggers and
  high-p_T (≥18 GeV/c) single-lepton trigger (lepton -> e or μ)
- Select 3 leptons or 2 leptons+isolated track
  - All objects central ($|\eta|<1$) in the detector and isolated (e,μ: excess energy/p_T<10%)
  - Third object as low as 5 GeV/c, but leading ones can be higher (10 or 15 GeV/c)
  - Keeping the tight and loose objects separately for optimizing the discovery and limit significance. Also angular cuts between leptons, MET, jet
- Signal region:
  - $76>M_{ll}>15$ GeV/c^2 and $M_{ll}>106$, MET>20, and low jet-multiplicity
    - ✓ Exclusion of low mass ***reduces photonic DY and Heavy Flavor***
    - ✓ Z-veto ***reduces the electroweak backgrounds***
    - ✓ jet-multiplicity cut ***cuts top and reduces QCD backgrounds***
- Main trilepton backgrounds: Diboson (61%), DY+γ (22%) , fakes (15%)
- Main systematics: Fake-rate (50%) and theoretical cross-section uncertainties

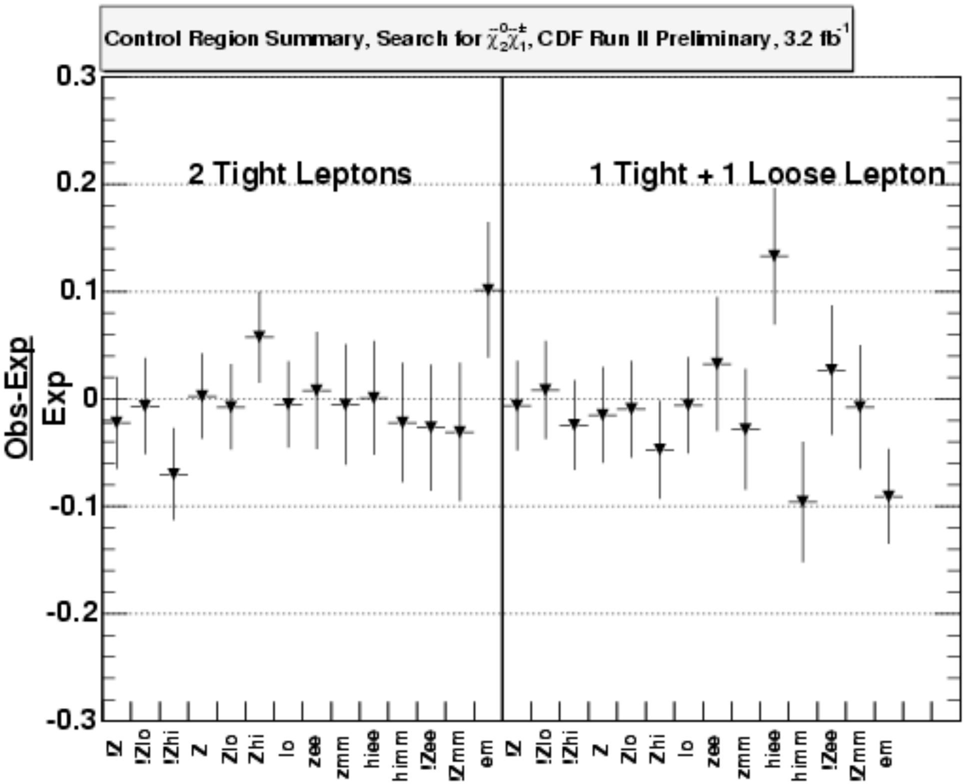
Control Regions



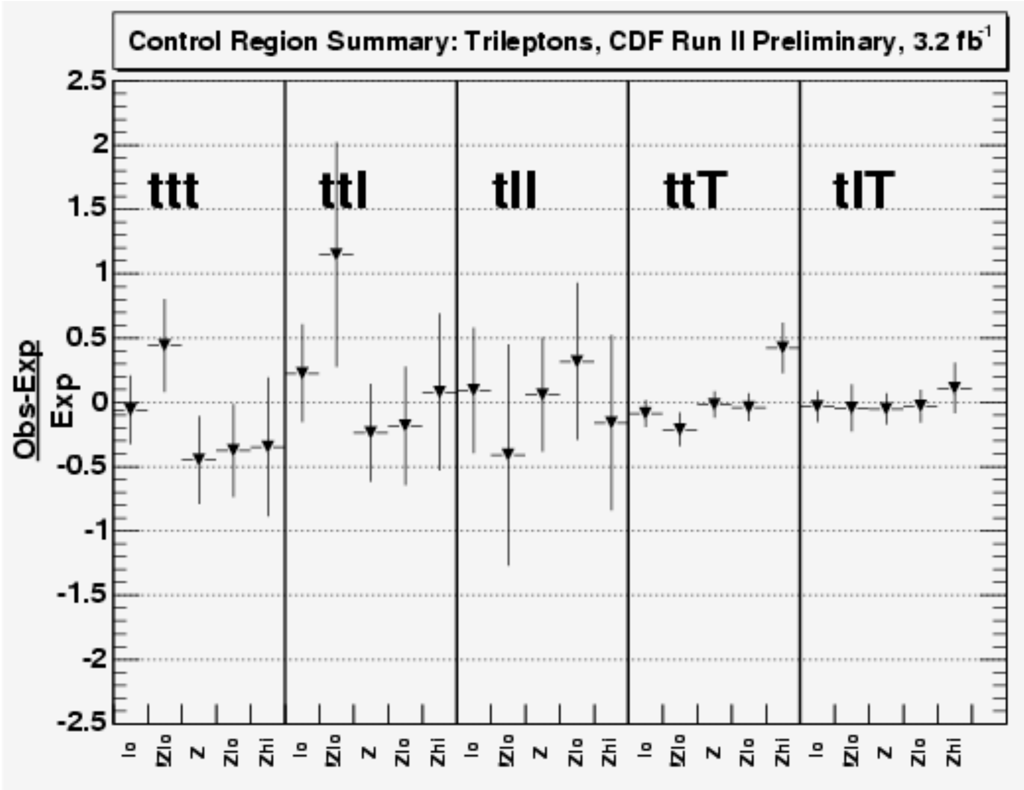
- Several control regions in the MET vs M_{ll} space are defined, with the extra requirement of low (<2) and high (>1) jet multiplicity
- All control regions are studied for both dileptons and trileptons

Control Regions Results

Dilepton control regions

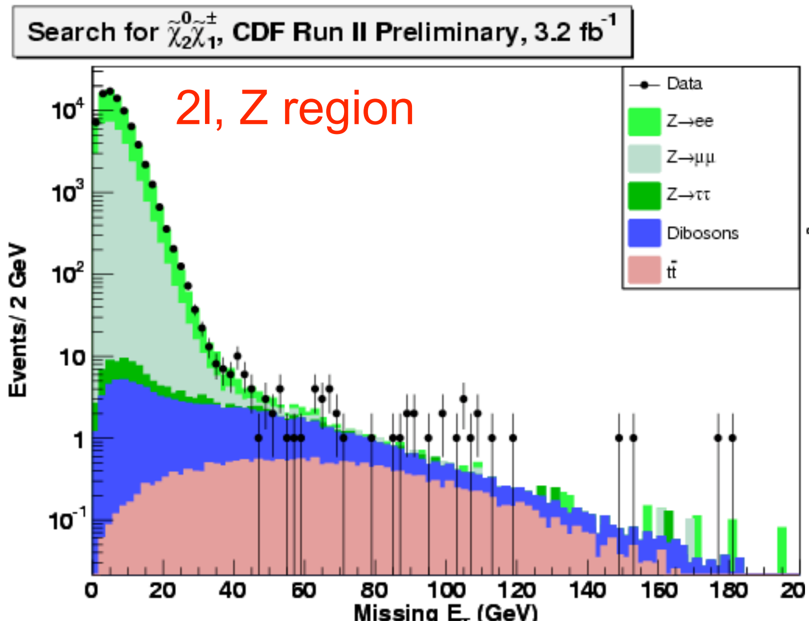


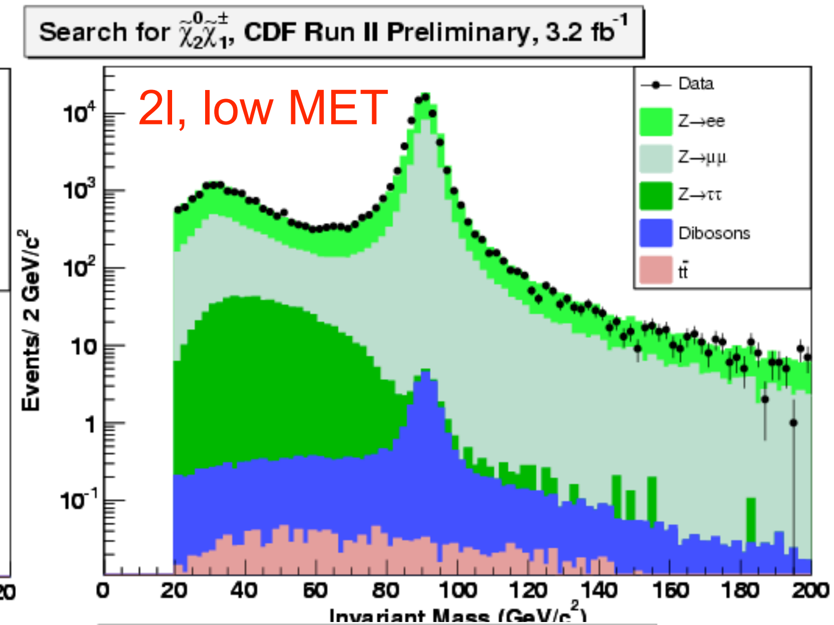
Trilepton control regions

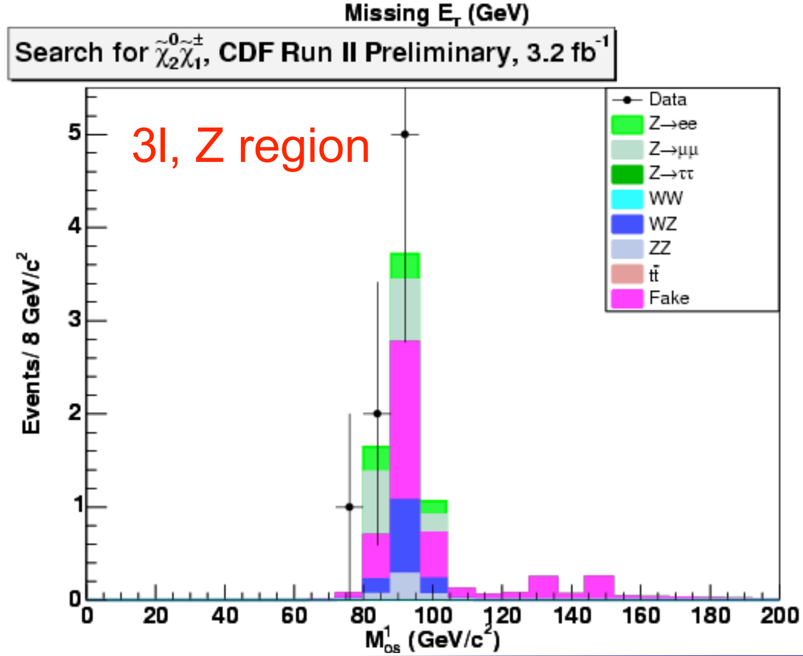


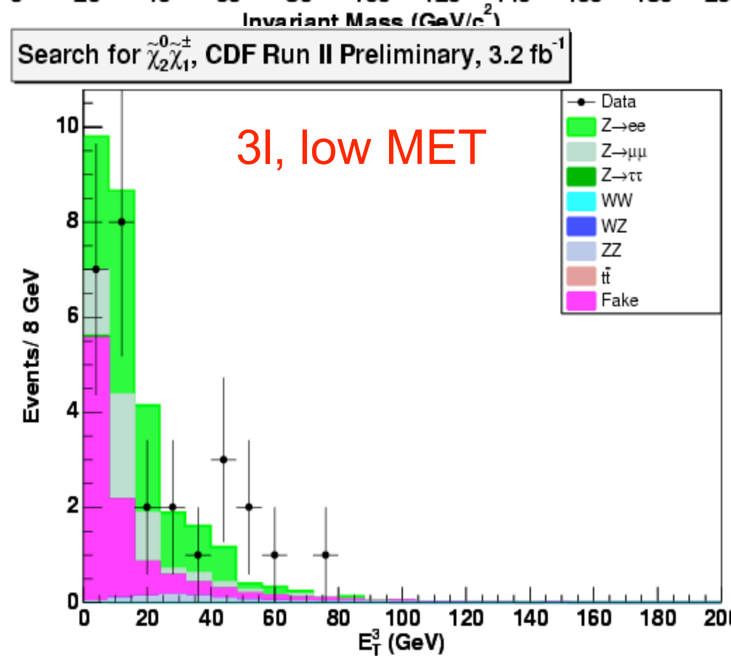
- Excellent understanding of the Standard Model backgrounds in all our dilepton and trilepton control regions

Some kinematics in control regions









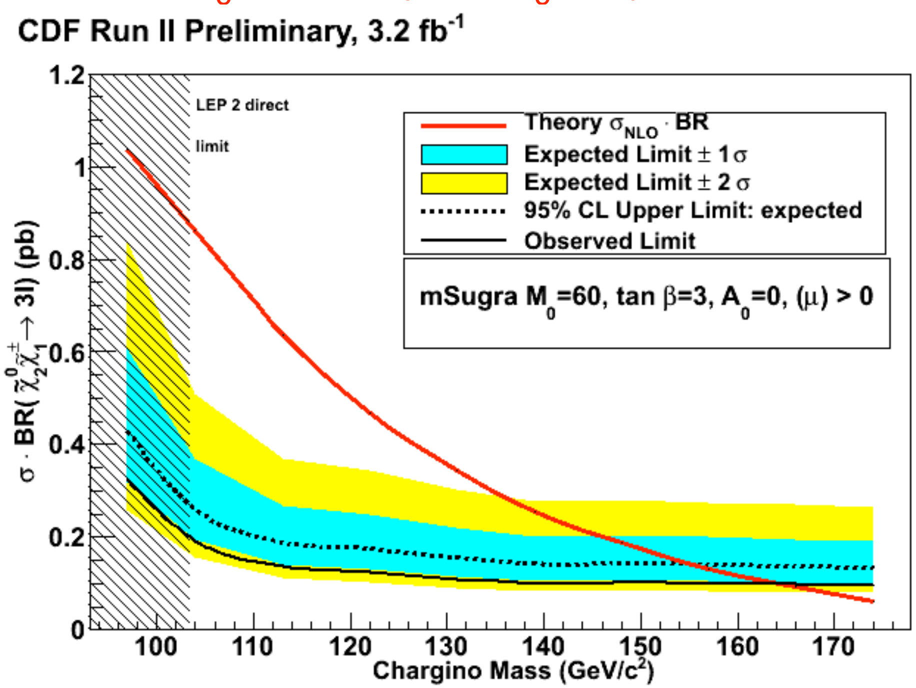
Result and limits

- Our counting result is consistent with the Standard Model

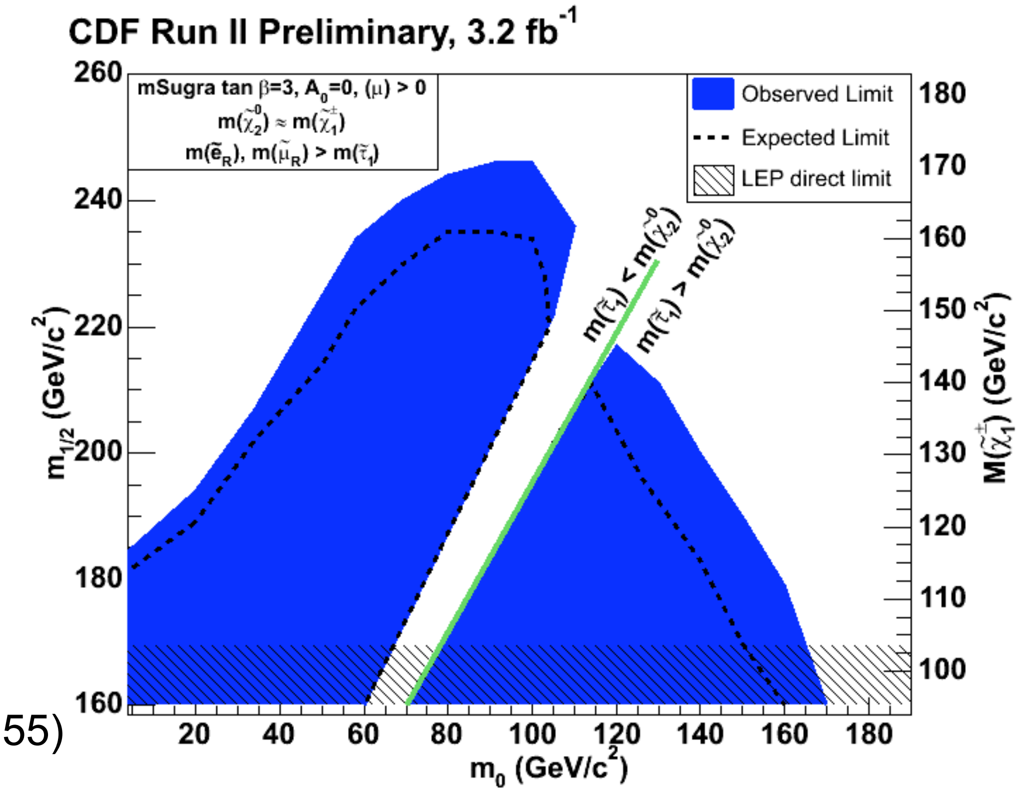
Analysis	Backg.	Signal	DATA
Trilepton	**1.5 ± 0.2**	7.4 ± 0.7	**1**
Dilepton+Track	**9.4 ± 1.4**	11.2 ± 1.1	**6**

m_0=60 GeV,
$m_{1/2}$=190 GeV,
tanβ=3, A_0=0, μ>0

(m_0=60 ,tanβ=3, A_0=0, μ>0)



(tanβ=3, A_0=0, μ>0)

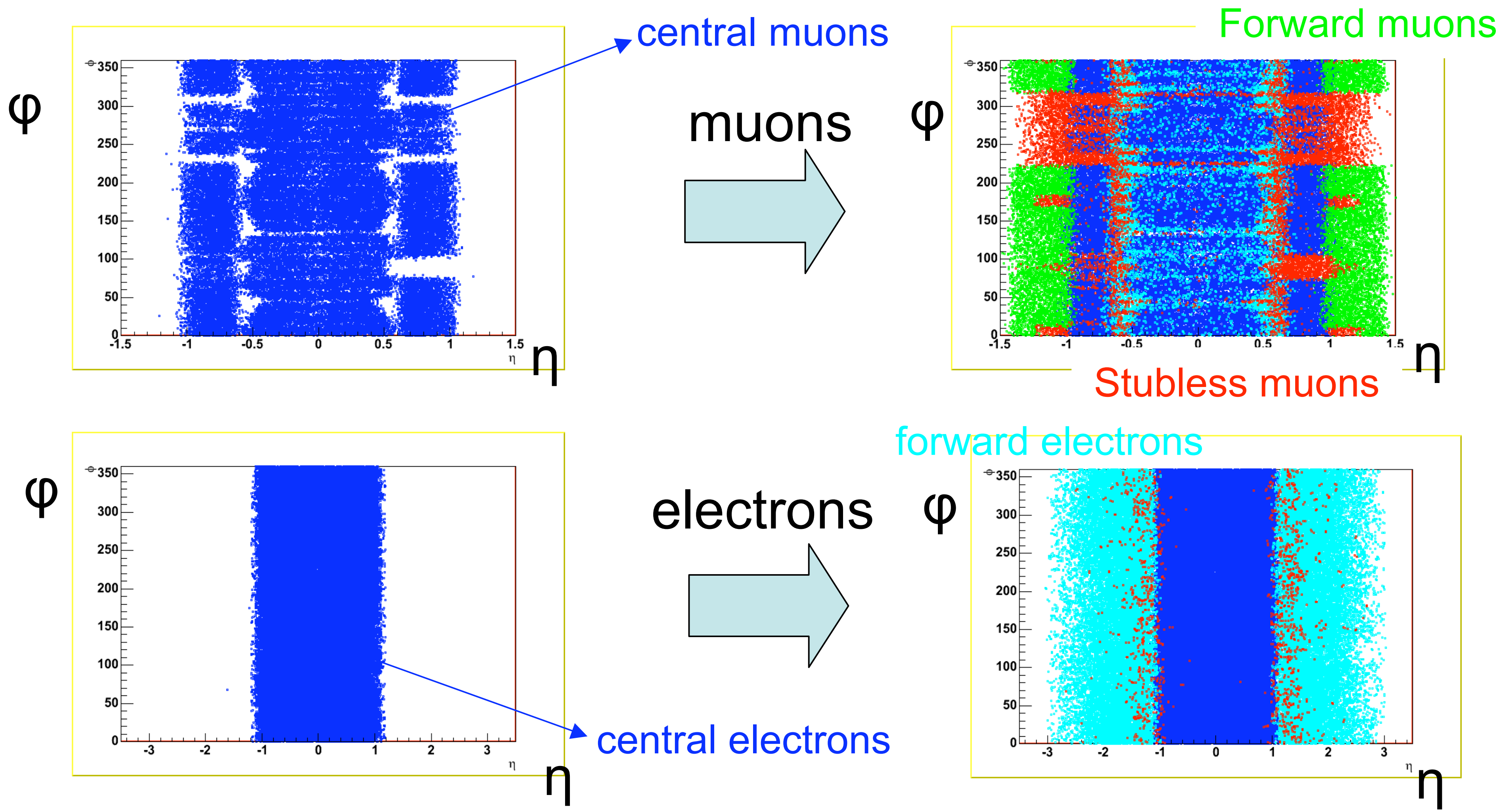


$M(\chi_1^\pm) >$ 164 GeV/c^2 at 95% CL (expected 155)

Current trilepton analysis improvements

- We are in the process of extending/improving the chargino-neutralino analysis (in addition to adding more data, currently 4 fb^{-1} in total, and new triggers)
- We expand geometrically
  - We include forward ($|\eta|>1$) regions of the detector
- We expand kinematically
  - Low-p_T and low-M_{ll}
- We include new objects
  - tau leptons
- Our goal is the completion of the most sensitive CDF analysis
  - For the greatest discovery potential
  - For the best limits settings
  - For setting benchmarks for the current LHC experiments

Increase coverage for muons and electrons

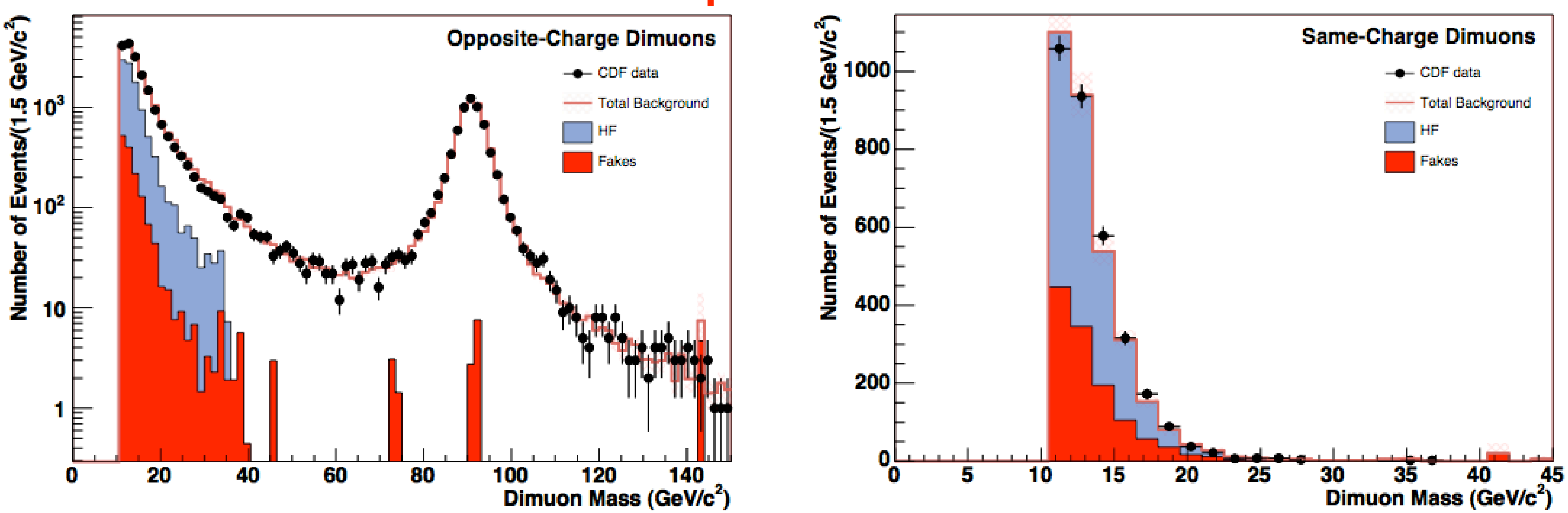


- We will use the full CDF detector, including the forward calorimeters and muon systems.
- The forward objects roughly double (triple) our dilepton (trilepton) acceptance

Lower lepton p_T and dilepton mass

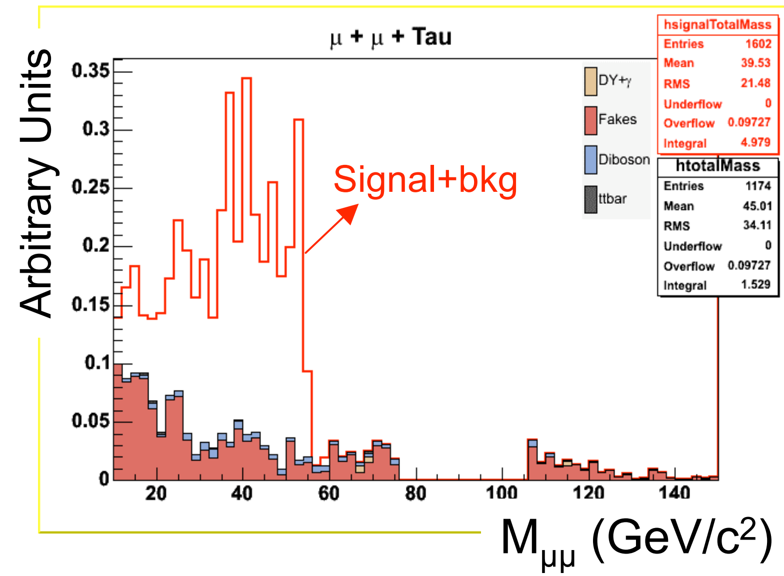
- Lowest p_T value for most objects will be 5 GeV/c and lowest dilepton mass will be 10.5 GeV/c^2. Also looser cuts for low-p_T leptons will be used
- Motivation: the signal is most probably there !!
  - Due to cascade SUSY decays and the preferable production of staus that decay to taus that decay to soft leptons
- This way we fully utilize the low-p_T dilepton triggers
- **Extra backgrounds: Heavy-flavor**. We have developed and tested a method that estimates the HF with data

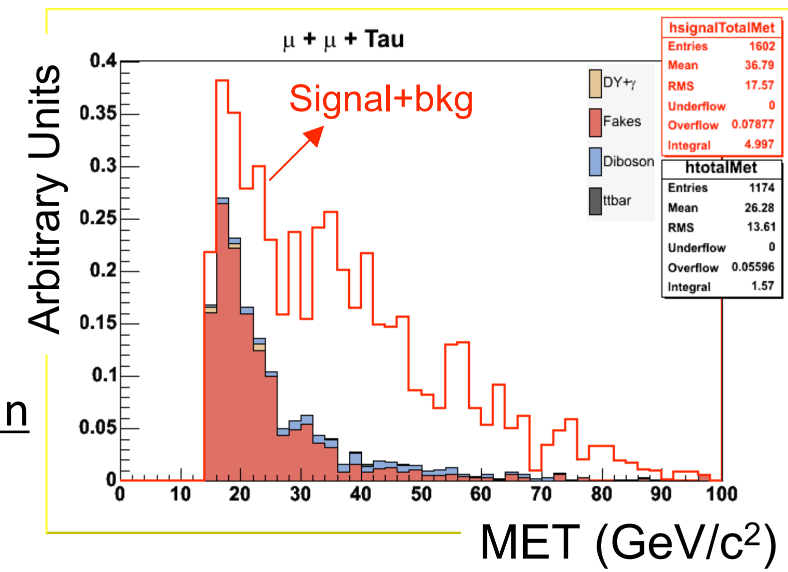
Example: 1 fb^{-1} dimuons Phys. Rev. D 79, 052004 (2009)



Inclusion of tau leptons

- For many SUSY scenarios and parameters the staus are the lightest sleptons
  - Especially for high tanβ
- <u>As a result, we expect many tau final states</u>
- We catch the leptonic decays of taus through the soft leptons (>5 GeV/c)
- We want to catch the hadronic decays of taus, by using tau objects
  - Initially for llτ, eventully for ττX decays
- We define a tau using 1 or 3 tracks (for 1 or 3 prong decays) isolated from extra hadronic activity
- For the [m_0=60 GeV, $m_{1/2}$=190 GeV, tanβ=3, A_0=0, μ>0] benchmark, <u>our sensitivity to third taus is better than that of third electrons!</u>





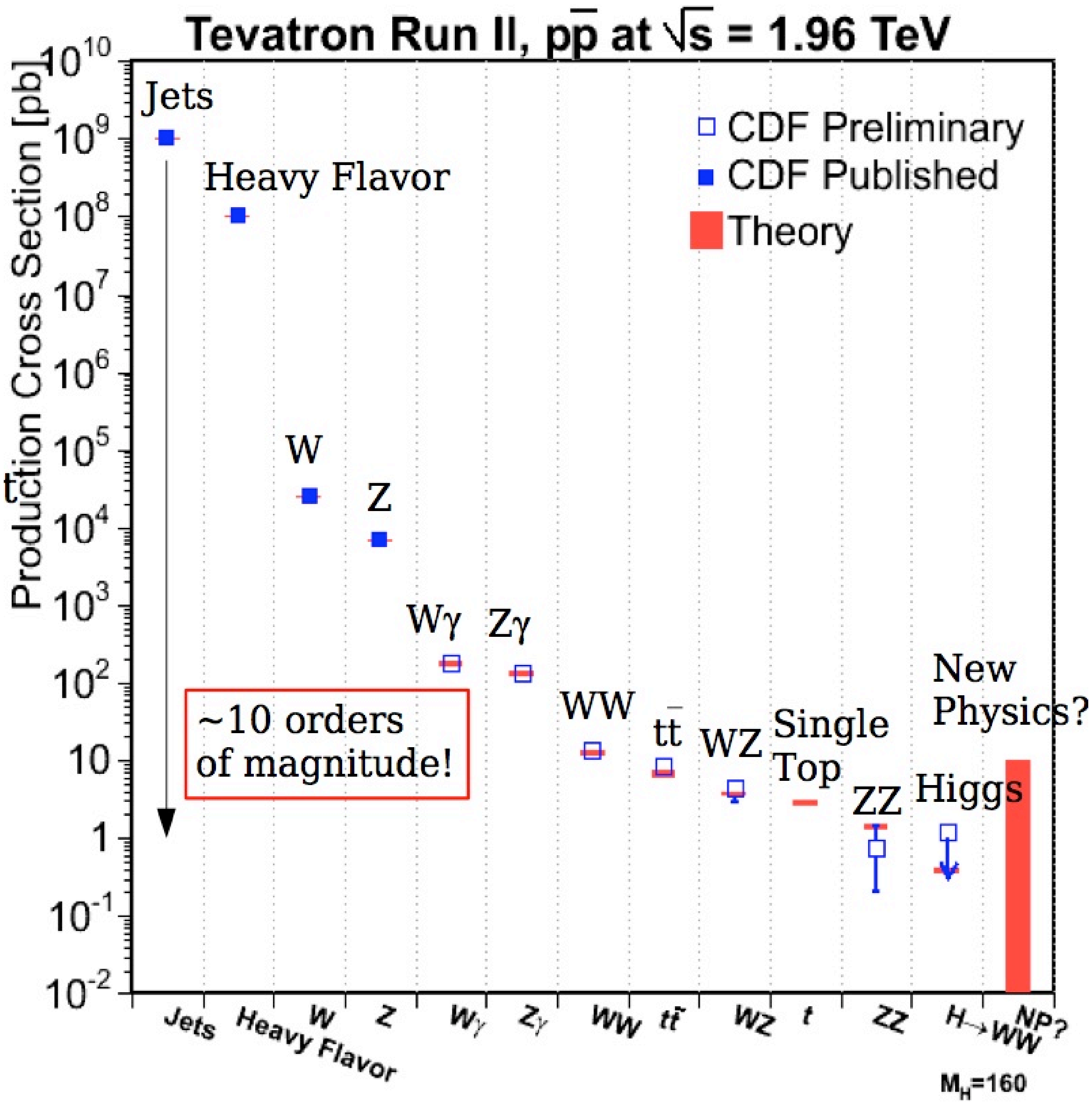
Conclusions

- We are searching for new-physics trilepton signal motivated by the chargino-neutralino analysis
- We have performed a trilepton+MET analysis with 3.2 fb^{-1} of CDF data
- We have not observed any discrepancy with the Standard Model expectation and we set mSUGRA limits
- We are in the process of considerably improving the analysis to maximize our discovery potential and limits-setting power
- So stay tuned because …

After all, the chargino is very close to FNAL

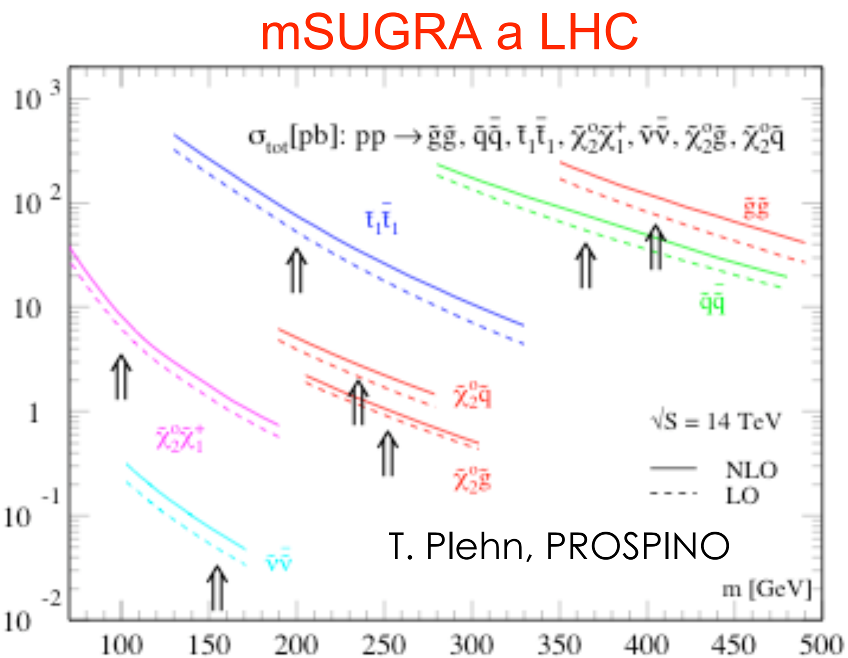
Back up

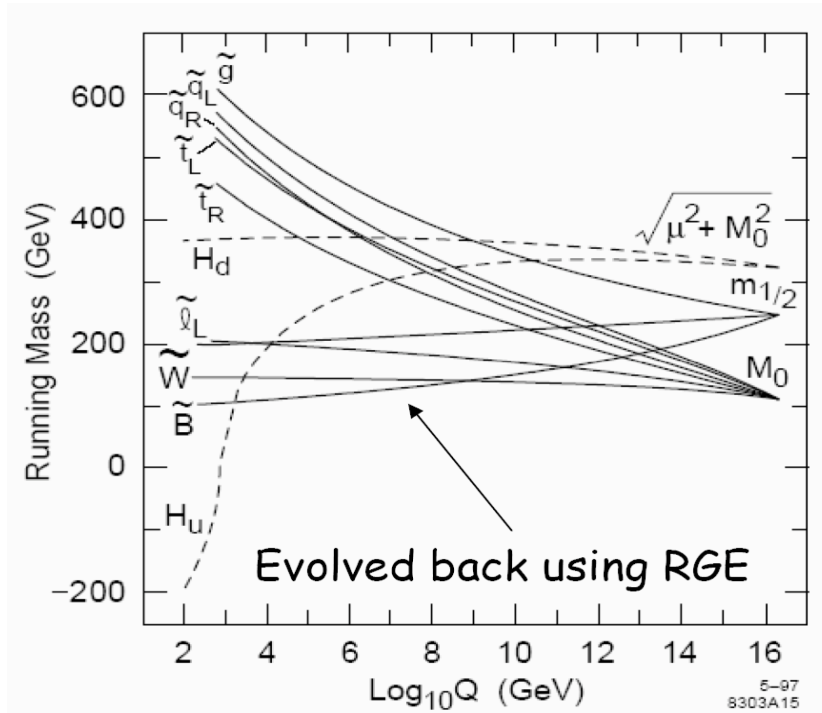
Feeling about the SM cross-sections



- But generic production is not enough:
- We care about the branching ratios to leptons
  - ~11%/flavor for W
  - ~3.5%/flavor for Z
- We care about the probability for jets to be mis-reconstructed as leptons
  - Depends on the jet and lepton identification requirements
  - 10^{-2} - 10^{-4}
- And we care about the trigger and reconstruction efficiency and detector acceptance

mSUGRA





- The free parameters are
  - m_0, the common sfermion mass
  - $M_{1/2}$, the common gaugino mass
  - tanβ, the ration of higgs vacuum expecation values
  - A, the trilear sfermion-sfermion-higgs coupling
  - Sign of μ, the higgs parameter scale

Checking one SUSY benchmark point

- This is point m_0=60 GeV/c^2, $m_{1/2}$=190 GeV/c^2, $\tan\beta$=3, A_0=0, μ>0
  - Benchmark used in CDF, Phys. Rev. Lett. 101, 251801 (2008)
- Spectrum created with Isajet 7.79
- The decay to leptons is really good and our acceptance even better
  - Neutralino goes 30% to selectron, 30% to smuon, 40% to stau
  - Chargino goes 2% to electron, 2% to muon, 2 % to tau, 92% to stau
- Cross section (prospino) equals to 0.47 pb.
- Masses:
  - Lightest chargino ~ 122 GeV/c^2
  - Next to-lightest chargino ~ 325 GeV/c^2
  - Lightest neutralino ~ 67 GeV/c^2
  - Next-to-lightest chargino ~ 125 GeV/c^2
  - Lightest higgsion ~ 100 GeV/c^2
  - Heavy higgsinos ~ 350 GeV/c^2

Cut definitions and event-breakdown

CDF RUN II Preliminary $\int \mathcal{L}dt = 2.0\ \text{fb}^{-1}$: Search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$

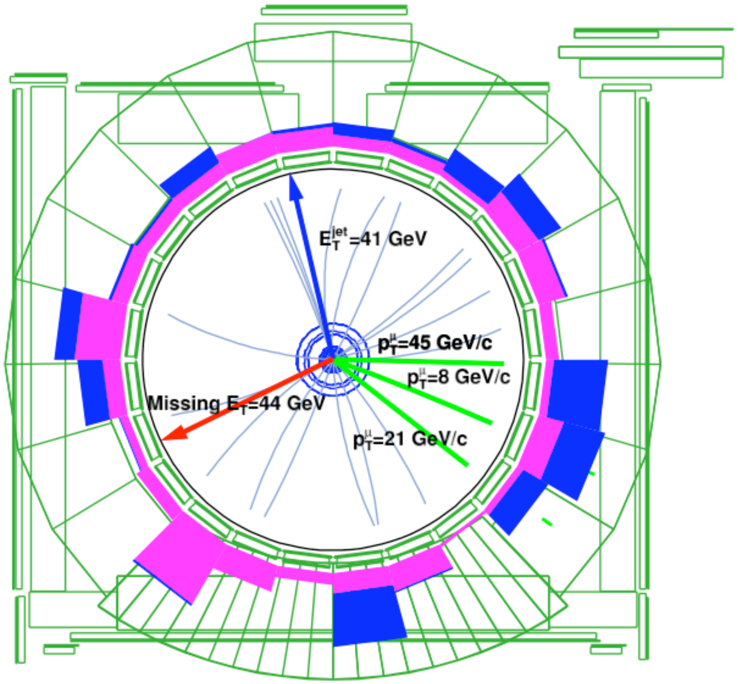
Channels	Selection	$(E_T/P_T)_{1,2,3} GeV$
3tight	3 tight leptons or 2 tight leptons + 1 loose electron	15, 5, 5
2tight,1loose	2 tight leptons + 1 loose muon	15, 5, 10
1tight,2loose	1 tight leptons + 2 loose leptons	20, 8, 5(10 if loose muon)
2tight,1Track	2 tight leptons + 1 isolated track	15, 5, 5
1tight,1loose,1Track	1 tight + 1 loose lepton + 1 isolated track	20, 8(10 if loose muon), 5

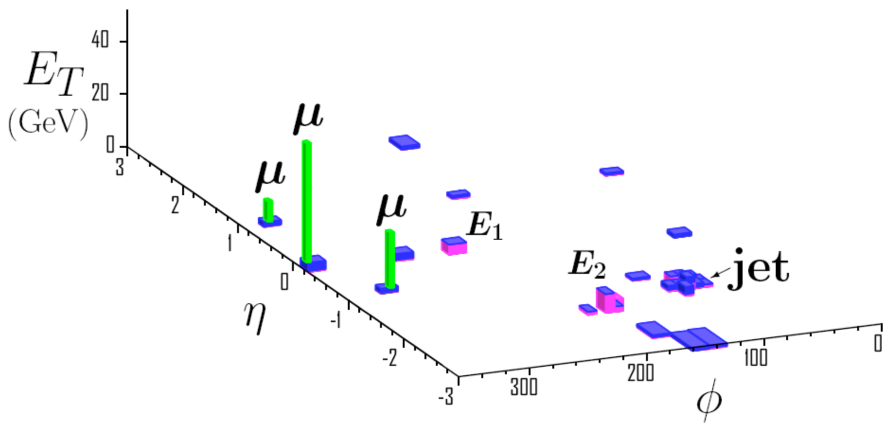
CDF II Preliminary, 3.2 fb^{-1}

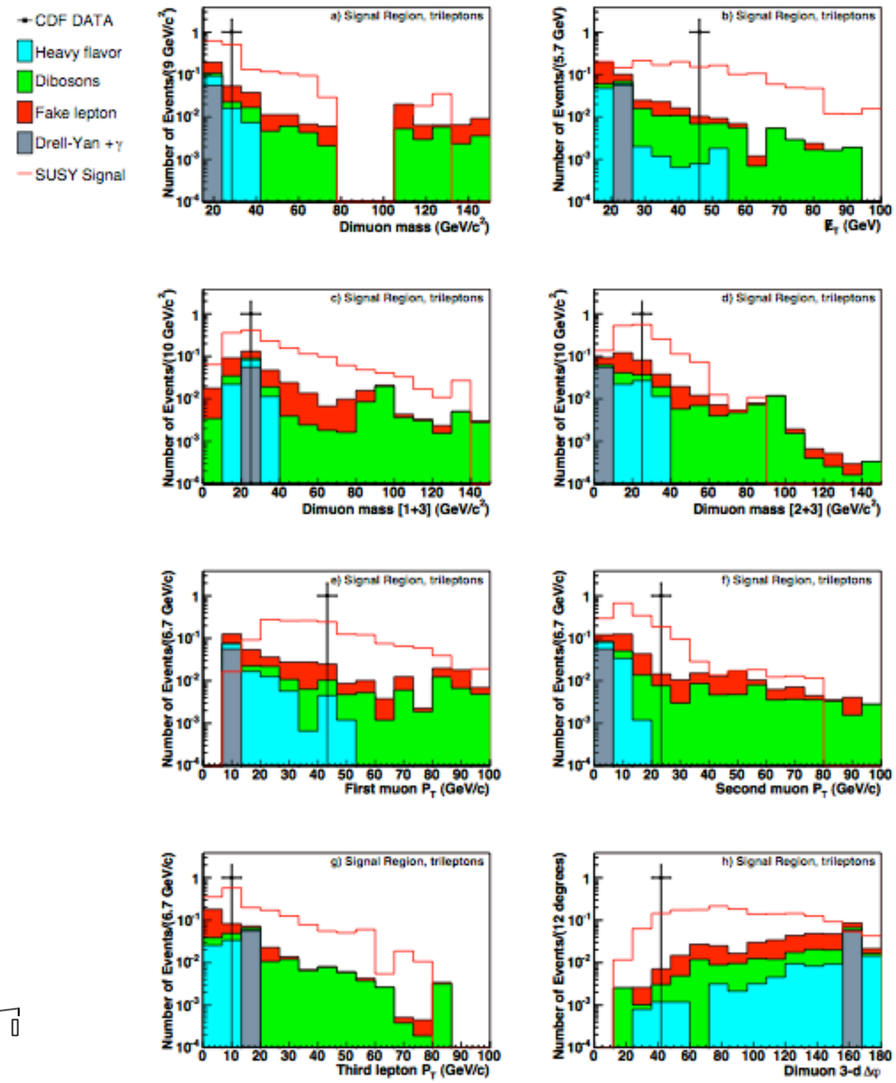
	$Z \to ee$	$Z \to \mu\mu$	$Z \to \tau\tau$	WW	WZ	ZZ	$t\bar{t}$	Fakes	Total Background	Signal Point	Observed
ttt	0.19	0.00	0.00	0.02	0.38	0.08	0.02	0.16	0.83 ± 0.18	3.64 ± 0.53	1
ttC	0.00	0.06	0.00	0.00	0.21	0.07	0.00	0.04	0.39 ± 0.08	2.62 ± 0.39	0
tll	0.00	0.00	0.08	0.00	0.10	0.03	0.01	0.03	0.25 ± 0.08	1.12 ± 0.19	0
Trilepton	0.19	0.06	0.08	0.02	0.69	0.18	0.03	0.23	1.47 ± 0.21	7.38 ± 0.68	1
ttT	1.33	0.27	1.10	0.53	0.24	0.11	0.29	1.98	5.85 ± 1.25	7.15 ± 0.96	4
tlT	0.83	0.60	0.52	0.40	0.07	0.07	0.14	0.91	3.53 ± 0.72	4.06 ± 0.57	2
Dilepton + Track	2.16	0.87	1.62	0.93	0.31	0.18	0.43	2.89	9.38 ± 1.44	11.21 ± 1.12	6

mSugra Signal point: $M_0 = 60, M_{1/2} = 190, \tan\beta = 3, A_0 = 0$

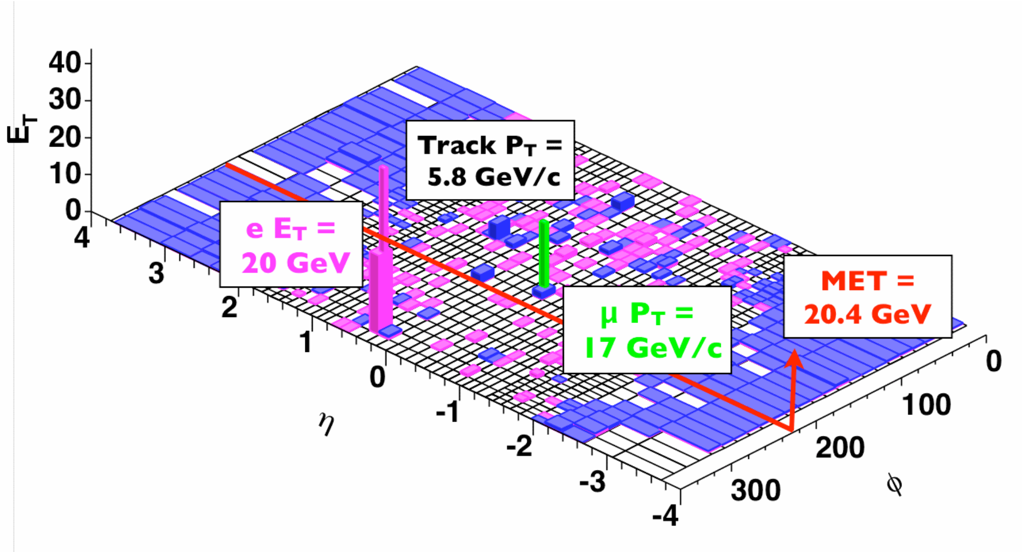
Event Display (1)

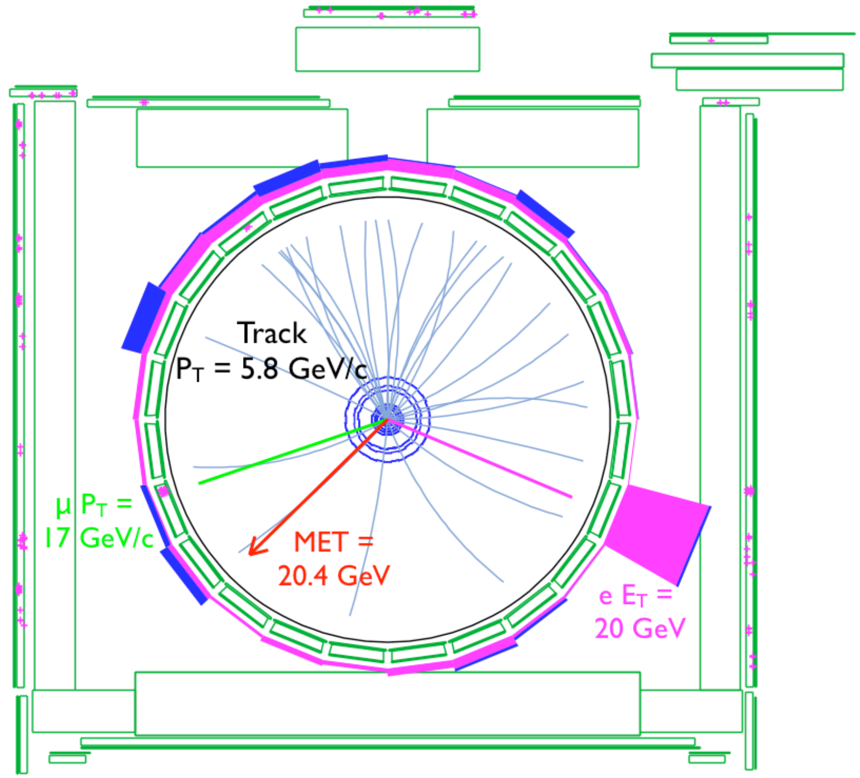






Event display (2)





Hadronic Tau reconstruction

- $|\eta|<1$
- E>20 GeV
- M<1.8 GeV/c^2
- N_{tracks} (inner cone)=1 or 3
- N_{tracks} (between inner and outer cone)=0
- $N_{towers} \leq 6$
- good tracking for seed track
- d0 cut on seed track
- track-EMcalorimeter matching with seed track